NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

COMMUNICATION MODULATION SIMULATORS:
AN ASSESSMENT

by

Heidi L. Gebhardt

June 1997

Principal Advisor: John Osmundson
Associate Advisor: Donald van Z. Wadsworth

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 1997	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE:: COMMUNICATION MODULATION SIMULATORS: AN ASSESSMENT	5. FUNDING NUMBERS
6. AUTHOR(S) Gebhardt, Heidi L.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

The military drawdown and budget cutbacks have created a greater emphasis on shorter, faster, and cheaper ways to do the mission. Modulation simulators have become a critical component in the evaluation and testing, and integration of new network, communications, and command and control technologies and applications.

This thesis evaluates five current commercial off the shelf products: OPNET Modeler by MIL 3 Inc.; COMNET III designed by CACI Products Company ; Extend by Imagine That Inc.; Workbench created by Scientific Engineering Software Inc.; and G2 from the Gensym Corporation. Each of the products is evaluated using twenty-five primary evaluation criteria. The evaluations include current costs, completeness, user interface and post analysis support methods, and they describe the basic features and distinctive characteristics of each product.

The capabilities of the products are compared, providing the reader with the knowledge to make an informed product selection based on the user's needs. A matrix of the products and the evaluation criteria provides a quick overview of the analysis.

14. SUBJECT TERMS COMNET III, OPNET Modeler, Workbench, Extend, G2.	15. NUMBER OF PAGES 77
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

COMMUNICATION MODULATION SIMULATORS: AN ASSESSMENT

Heidi L. Gebhardt
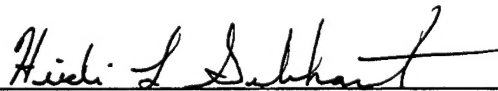Captain, United States Army
B.S., Pennsylvania State University, 1988

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEM TECHNOLOGY
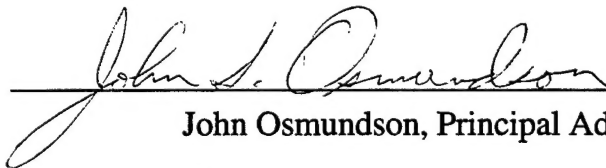### (Command, Control and Communications)

from the

NAVAL POSTGRADUATE SCHOOL
June 1997

Author: _____
Heidi L. Gebhardt

Approved by: _____
John Osmundson, Principal Advisor

_____
Donald van Z. Wadsworth, Associate Advisor

_____
Dan C. Boger, Chairman
Command, Control and Communications Academic Group

ABSTRACT

The military drawdown and budget cutbacks have created a greater emphasis on shorter, faster, and cheaper ways to do the mission. Modulation simulators have become a critical component in the evaluation and testing, and integration of new network, communications, and command and control technologies and applications.

This thesis evaluates five current commercial off the shelf products: OPNET Modeler by MIL 3 Inc.; COMNET III designed by CACI Products Company's; Extend by Imagine That Inc.; Workbench created by Scientific Engineering Software Inc.; and G2 from the Gensym Corporation. Each of the products is evaluated using twenty-five primary evaluation criteria. The evaluations include current costs, completeness, user interface and post analysis support methods, and they describe the basic features and distinctive characteristics of each product.

The capabilities of the products are compared, providing the reader with the knowledge to make an informed product selection based on the user's needs. A matrix of the products and the evaluation criteria provides a quick overview of the analysis.

TABLE OF CONTENTS

ACKNOWLEDGMENT

The author would like to thank Professor John Osmundson for his support, guidance and patience during the preparation of this thesis.

EXECUTIVE SUMMARY

The drawdown and budget cutbacks have created a situation where the military must use alternate means to evaluate existing and emerging communications, computer and information systems. It is no longer feasible to build computer, communications and information systems solely for testing and evaluation purposes. Money, equipment, soldiers and time are not available to disconnect existing information systems for testing and evaluation.

It is standard practice to utilize software simulation, including hardware and man-in-the-loop, to expedite development, testing, and evaluation of computer, communication, and information systems. This thesis examines the current state-of-the-art *modulation* simulators, so-called because signal modulation is required to communicate information.

Modulation simulation is a computerized method for modeling a current or future communications, computer, or command and control system. Modulation simulators assist the user in designing, evaluating, testing, and reconfiguring a system. It is much less expensive to model a new system with a modulation simulator than to physically build a demonstration example. Modulation simulators allow for parameter variation, protocol variation, load testing, and reconfiguration all within the computer. Modulation simulators allow users to examine emerging system's interfaces with current military, commercial and joint networks, and they provide a method for testing futuristic technologies. Additionally, they enable the user to evaluate network performance, to test the effects of system outages, to stress the system under peak loading, and to see how a network would react as equipment is moved, simulating the flow of the battle or OOTW (Operations Other Than War).

An analysis of five of the current commercial off the shelf software modulation simulator products provides the modeler with the information needed to make an informed product selection. The five products, OPNET Modeler developed by MIL 3 Inc., COMNET III by CACI Products Company, Extend created by Imagine That Inc., Workbench by Scientific and Engineering Software Inc., and G2 from the Gensym Corporation, were evaluated against twenty-five various criteria. The following table

provides a non-weighted comparison/evaluation of the products and some general overview information. A rating of 1, the lowest, to 5, the highest, has been established for each evaluation criteria.

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
General Usage	Comm Networks, Computer Systems and Applications, and Distributed Systems	Network Planning Tool, LAN/WAN	Simulation Tool	System Level Simulation Tool	Intelligent Real Time Systems
Vendor	MIL 3 Inc.	CACI Products Company	Imagine That, Inc.	SES	Gensym Corp.
Platforms	Sun SPARC, DEC, HP UX, SGI, Windows NT	PCs (Windows NT and Windows 95), UNIX, DEC, HP UX, SGI, AIX, Solaris	PCs (Windows 3.1, NT and Windows 95), Macintosh	Sun Micro-stations, IBM, HP	Digital, IBM, HP, Sun Micro-stations, PC's (Windows NT and Windows 95)
Price Commercial University	$18,000.00 $600.00	$48,500.00 $3000.00	$695.00 $350.00	$23,500.00+ $500.00	$40,800.00 $500.00
Accessibility	3	3	3	2	3
Completeness	5	3	4	4	4
Configuration Management	5	4	4	5	5
Cost	4	1	5	3	2
Data Input Methods	5	5	5	5	5
Data Reduction	5	5	5	5	3
Documentation	4	3	3	4	3
Ease Of Use	3	4	3	3	2
Experimental Design	4	2	5	3	3
Extendibility	4	2	4	5	5
Extensibility Of Results	5	2	4	4	4
Fidelity	5	4	5	5	5
Flexibility	4	4	4	4	4
Interoperability	4	2	4	4	4
Miscellaneous	4	2	2	2	2
Operational Environment	5	5	5	3	5
Post Analysis Support	5	5	3	4	5
Reliability	5	5	5	5	5
Security	3	1	1	1	3
Software	3	3	3	4	4

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
Training / Tutorial	4	4	4	3	2
Troubleshooting Assistance	3	3	4	5	3
User Interface	4	5	5	4	4
Validation	5	5	5	5	5
Verification	5	5	5	5	5
Non Weighted Totals	106	87	100	97	95

Each of the five products analyzed has special characteristics and qualities. The products' functions and capabilities vary, making each product perfect for a different scenario.

CACI's COMNET III is the best choice for modeling a wide area network or local area network. COMNET III provides all the familiar computer network icons in a user friendly environment to enable the user to quickly model and analyze a computer network. COMNET III, however, does not model communication or information systems. Nor does COMNET III model the innards of a computer.

MIL 3 Inc. developed OPNET Modeler, which can model computers, communication and information systems from the network through the process and state levels. Numerous libraries are available to assist the modeler. OPNET's primary disadvantage is its fixed run speed. This can cause extensive time delays during a simulation run of a detailed model.

SES' Workbench, like OPNET, can be used to model communication, computer, and information systems. In addition, Workbench can be used to model numerous other types of systems, to include queues, electric flow, water pollution, etc. The ability to model more than just communication, computer and information systems provide an added flexibility to the modeler.

Extend, developed by Imagine That Inc., is similar in its capabilities to Workbench, in that it can also model any type of system. Extend, however, provides a more user friendly environment for the modeler. Besides the documentation's ease of use, the menu setup has a more logical flow. Workbench, through the use of sub-

modules, can model to a smaller level of detail than Extend, and Workbench can handle larger sized models.

G2, also similar to Workbench in its system modeling capabilities, is in a class by itself. G2 utilizes an object oriented modeling environment with a structured natural language. This product is a great selection for a beginner or non-programmer. Object oriented modeling enables the modeler to design the level of fidelity and complexity to be modeled. G2 includes a wide range of knowledge bases or libraries, though the labeling is puzzling. G2/object oriented modeling is not an easy product/modeling method to learn.

In making a selection, it, also, is essential to look at the capabilities and characteristics of the modeler. Programming skills may influence the product selection. All five of the products are icon and menu oriented. COMNET III provides the smallest programming interface, and G2 has an easy to learn structured natural language. OPNET, Extend, and Workbench each use a modified version of the C language. Workbench presents the user with the largest interface with the model's code, and provides the user with the most programming opportunities.

The user must take into consideration the various characteristics of the system to be modeled and the capabilities of the modeler. This combination must be compared to the analysis of the products to correctly select the proper software modulation simulator for the mission.

I.   INTRODUCTION

A.   MILITARY AND MODULATION SIMULATORS

It is standard practice to utilize software simulation, including hardware and man-in-the-loop, to expedite development, testing, and evaluation of computer, communication, and information systems. This thesis examines the current state-of-the-art *modulation* simulators, so-called because signal modulation is required to communicate information.

Modulation simulation is a computerized method for modeling a current or future communications, computer, or command and control system. Modulation simulators assist the user in designing, evaluating, testing, and reconfiguring a system. It is much less expensive to model a new system with a modulation simulator than to physically build a demonstration example. Modulation simulators allow for parameter variation, protocol variation, load testing, and reconfiguration all within the computer. Modulation simulators allow users to examine emerging system's interfaces with current military, commercial and joint networks, and they provide a method for testing futuristic technologies. Additionally, they enable the user to evaluate network performance, to test the effects of system outages, to stress the system under peak loading, and to see how a network would react as equipment is moved, simulating the flow of the battle or OOTW (Operations Other Than War).

Most organizations currently using modulation simulators are developmental, testing and evaluation, or acquisition oriented. Some examples include: Directorate of Combat Development, Fort Gordon, Georgia; Joint Interoperability Testing Command, Fort Huachuca, Arizona; and Defense Information Systems Agency, D8, Arlington, Virginia.

Modulation simulators could, also, be utilized by tactical operations staffs. Networks designed for tactical exercises could be modeled, tested, and evaluated for trouble spots prior to deployment of personnel and equipment. Networks could be tweaked for optimal reliability prior to installation. This would save the military precious time and money.

1

B.   SCOPE

The focus of this thesis is on commercial modulation simulators. Budget cutbacks have reduced military software development resulting in most units turning to Commercial Off The Shelf (COTS) products.

This thesis evaluates five of the current commercial modulation simulators: OPNET Modeler 3.0 by MIL 3 Inc.; COMNET III by CACI Products Company; Extend by Imagine That Inc.; Workbench by Scientific and Engineering Software Inc.; and G2 by Gensym Corporation. Each product is evaluated against twenty-five assessment criteria. See Appendix. A score of 1 to 5 (5 is the best) will be assessed for each criteria. The objective is to provide the reader with the information required to intelligently select the most useful modulation simulator for a specific mission.

The software product chapters, Chapter II through Chapter VI, include an overview of each product and a detailed evaluation of the product based on each of the criteria and sub-criteria. Chapter VII is the analysis/comparison chapter which summarizes the results and provides the reader with a basis for making an informed selection. Examples are provided in Chapter VII to assist the reader with how to effectively select the correct software product.

Evaluations are based on a hands-on utilization of each product, tutorials, world wide web and user demonstrations, all available documentation, and interviews with users, sales representatives, and technical support personnel.

C.   PRODUCT SELECTION

The software products selected were based upon availability to the author, current or proposed usage in the military, and experienced users' recommendations. Many of the products can be used to model a wide range of systems. This thesis concentrates on simulating communication, computer and information networks. This includes computer Local Area Networks (LANs) and Wide Area Networks (WANs), current military communication systems (Mobile Subscriber Equipment, Digital Group Multiplexing Equipment, SINCGARS, etc.) and message switching networks. Additionally, the thesis

2

examines the software product's interface capabilities for modeling joint and emerging technologies.

II.   OPNET MODELER

A.   INTRODUCTION

OPNET Modeler™ by MIL 3 Inc. is a computer aided engineering system for the design, simulation, and analysis of communication networks, computer systems, applications, and distributed systems. OPNET was introduced by MIL3 Inc. in 1987. Over 500 organizations, both civilian and Department of Defense, are currently using OPNET (MIL 3, 1987).

OPNET Modeler has a detailed object-oriented environment. It utilizes a windows user interface with icons, drop down menus and text editors for inputting the network. OPNET provides the user with the flexibility to model top-down, bottom-up or middle-out.

OPNET provides the user with the ability to model from the Wide Area Network (WAN) down through the process and state level. The process and state level is used to model the actions, changes, functions, and conditions of the basic components of a model. Various degrees of modeling provides the user with the added flexibility for modeling current or designing future communication and computer networks, systems and applications.

The following information is gathered from the UNIX on-line documentation, the MIL 3 Inc. world wide web page, the MIL 3 Inc. sales pamphlets, UNIX on-line tutorials, and telephonic interviews with sales personnel.

B.   ASSESSMENT CRITERIA

1.   Accessibility

OPNET Modeler can be installed on these platforms: Sun SPARC Solaris 2X; Sun SPARC Sun OS; Digital Equipment Corporation OSF/1; Hewlett Packard UX; Silicon Graphics IRIX; and Intel based implementations of Windows NT 3.5.1.

OPNET requires 75 megabytes (MB) of disk space for the software and 32 MB of Remote Access Memory (RAM). MIL 3 Inc. recommends 120 MB of disk space and 64

MB of RAM. OPNET requires access to an ANSI C compiler, which is included with the Solaris and Sun packages.

2. Completeness

OPNET Modeler is a comprehensive product. It models computers, software, WANs, Local Area Networks (LANs), data channels, or any other systems, applications or processes the user wishes to create. It includes the ability to model current and future technologies.

OPNET includes these protocol libraries: Ethernet, Token Ring, Fiber Distributed Data Interface (FDDI), Asynchronous Transfer Mode (ATM), Frame Relay, X.25, Link Access Procedure-Balanced (LAPB), Transmission Control Protocol (TCP), Internet Protocol (IP), User Datagram Protocol (UDP), Routing Information Protocol (RIP), Distributed Queue Dual Bus (DQDB), High Speed Serial Bus (HSSB), In-vehicle Communication Bus, Advanced Mobile Phone Service. Connectionless Network Protocol (CLNP), Transport Protocol 4 (TP4), and Global System for Mobile Communications are all available from third parties.

OPNET models multiple client/server applications (email, database, file transfer, etc.), peer-to-peer protocol delays, server backlogs, and transaction response time and throughputs. It, also, models satellite systems and mobile communications nodes.

Some military system libraries are available for this product. These are available through various Department of Defense agencies.

3. Configuration Management

The user is responsible for managing input and output files. Separate probes will have separate output files. However, a rerun of a model will overwrite existing output files.

The user can graphically display the Network, Node, or Process levels of the model. Each layer provides the user with a different degree of the model's detail.

4. Cost

OPNET Modeler is available commercially for $18,000.00. This includes all of the current commercial libraries and 90 days of maintenance and technical support.

Additional technical and upgrade support is available for $3,000.00 per year. The university edition is available for $600.00 per year.

MIL 3 Inc. offers a free one day training seminar. They, also, have a three day OPNET Modeler course available in Washington, DC for $1,500.00. Customized training can be requested at the user's location. The pricing of this option is dependent on the location, facilities, and instruction requested.

5. Data Input Methods

OPNET, in addition to using predefined Generator Modules (Ideal and Clock), uses stochastic traffic sources, based on a user selected probability function, for creating message inter-arrival times, and uses deterministic sources to specify exact times for message/packet generation. A regenerative source can be used to create "bursty" transmissions. Tables are used to prompt the user for data through out the development of the model.

External Model Access includes the capability to extract data from another model. (See Interoperability for additional information)

6. Data Reduction

OPNET Modeler provides immediate accessibility to probe (data collection method) results. This data can be formulated into graphs and reports. The probes are user selected and include node statistics, link statistics, global statistics, and simulation attributes.

The following probability distributions are available in OPNET Modeler:

- Bernoulli
- Erlang
- Poisson
- Chi-Squared
- Exponential
- Uniform
- Constant
- Normal
- Uniform-Integer

These can each be utilized via menu options.

7. Documentation

On-line documentation is included with the UNIX packages. Hard copy documentation can be purchased for $500.00 a copy.

The documentation is very detailed and informative. It includes a comprehensive tutorial, a user's manual, two volumes on modeling, and two volumes of the OPNET Modeler simulation kernels.

No design specifications were available.

8.   Ease Of Use

This product is fairly complicated to the new user. OPNET Modeler has such detailed capabilities it is difficult for an inexperienced user to quickly grasp all of its qualities.

OPNET Modeler enables the user to model events at the process and state level. The user continues with the nodal model and then integrates it all together in a network. This provides the user with very powerful capabilities. The user can vary the degree of depth of the programming parameters and events. The user, also, has access to the entrance and exit criteria of the states. The process and state level is the most basic breakdown of an element of a system. This enables the user to establish the specific conditions required to enter or exit a state of a system. This access is entirely in Proto-C™, a computer language very similar to C.

The manuals are extremely helpful but are oriented at the programmer level. Many modeling concepts are just assumed.

Set up and run time depend on the model. The basic models, only a few nodes, contained in the tutorial required between one and three hours of setup. Each of these only took a few minutes to run.

It is difficult to adjust the speed of the simulation clock. OPNET is designed to run as fast as it can. The total execution time is dependent on the total number of events, the complexity of each node and state, and the type of platform the simulation is being executed on. The user can speed up the simulation slightly by leaving out the debugging option during the execution. Also, the simulation can be forced to run at real time by establishing a comparison of the game clock with the real clock.

9.   Experimental Design

This product allows the user to execute iterative runs. Various probes can be set up for each of the runs. Separate output data files must be established prior to the

8

execution. State and process level modeling enables the user to develop models of emerging technologies.

10. Extendibility

OPNET can easily be modified. The user must first access the desired level to be altered, then right click on the item to be altered. This provides the user with the parameter menu. Additionally, OPNET offers the option of an attributes menu. This menu will allow the user to input specific numbers immediately prior to the run's execution.

OPNET Model uses Proto-C™ coding. Immediate access by the user to the entire model's code is not available. The user has open access to the entrance and exit coding for the state diagrams. Also, if an error occurs during compiling or execution, a text editor with the subroutine containing the error will be accessible to the user.

11. Extensibility Of Results

OPNET Model's ability to model at the state level enables the user to literally create any communication or computer system.. Traffic flow, architectures, software, protocols and data channels can be modeled. This program is limited by the user's creativity, modeling and programming skills. Communication and computer icons can be modified to model alternate architectures.

12. Fidelity

This product provides results consistent with the input parameters and models. Models can be developed with various degrees of detail.

13. Flexibility

Nodes can simulate movement and outages during run execution. Outages can be triggered by counters, probability distributions or the game clock. Movements can be simulated via timed outages.

Once the network is modeled it takes little time to make modifications.

14. Interoperability

OPNET has an External Model Access (EMA). EMA is a technique of accessing a model external to the OPNET program (MIL 3, 1989-1996, pp. EMA-3). This includes

creating a model, modifying a model, or just extracting data from a model. This is all supported via C programming language functions.

OPNET, also, has an External Compiler Interface (ECI). ECI permits the interfacing with third party compilers and linker programs.

15. Miscellaneous

Map overlays are available. However, they only provide a concept for the geographical locations of WANs, satellite equipment and footprints, and mobile cell layouts. There is no integration of equipment with terrain density or elevation.

Outages can be implemented via triggers, probability distributions or timed events. These can be programmed to be permanent or merely timed events.

OPNET can, also, model atmospheric propagation among satellite links, and airborne communication systems.

16. Operational Environment

The portability of the product is dependent on the computer platform. All platforms available are COTs.

17. Post Analysis Support

OPNET Modeler provides a wide variety of reports and graphs. The data collected is user selected via probes. Probes are established to collect data on various points in the network. Multiple probes can be utilized during the same run. Probe types are: node statistics, link statistics, global statistics, and simulation attributes.

The user can view the probe results with multiple or single output vectors. These vectors are selected by the user and displayed as traces, or graphs. OPNET Modeler's analysis tool supports a variety of calculations: histograms, probability distribution functions, cumulative distribution functions, and confidence intervals. Additionally, the user can create mathematical filters to help evaluate the data.

This program enables the user to export the results with encapsulated Postscript files or TIFF files to desktop publishing packages.

18. Reliability

OPNET Modeler is a Proto-C based product with icon and menu user interfaces. It executes in its own run time environment. Repeat runs produce consistent results.

19. Security

OPNET provides a restricted access security. Three types of users can be established. A basic user can run a model, but can not view the model in OPNET Editor. An inspector has basic user permissions plus the ability to "inspect" the model with certain interface procedures. A full user has complete access to the model and can edit the model via the OPNET Editor.

20. Software

OPNET Modeler is an object-oriented program introduced by MIL 3 Inc. in 1987. The source software is unavailable to the user. The user can program entrance and exit criteria for states with Proto-C. Proto-C is very similar to the C language. The user is provided access to some programming code in the event of an error. This is only to assist the user in troubleshooting the fault.

21. Training / Tutorial

The tutorial is comprehensive and informative. It takes the user step by step through the menus and model development of various types of networks. Some of the menus were incorrectly labeled in the tutorial, but the correct menu was pictured and the correct steps to reach the menu were given. The tutorial provides the user with a intermediate knowledge of the product. Someone with little or no modeling background would have a difficult experience using the product after the tutorial. It is written for a semi-experienced modeler/programmer.

22. Troubleshooting Assistance

Troubleshooting is difficult. All troubleshooting is oriented to the programmer. The documentation provides a basic overview and helps the user to locate the cause of the fault. Errors are listed by line of code, which is immediately displayed for the user. Various options are available within the animation probe to enhance the user's

troubleshooting capabilities. Assistance is available by phone, email, and through the world wide web.

23. User Interface

The user interface is a mixture of windows, menus, icons, and text editors. A window listing the current functions of the mouse buttons is provided at the bottom of the screen. A command window informs the user of the current status of the screen. Multiple levels can be open at the same time, and a recirculate button permits the user to move freely from level to level. The numerous menus can be confusing to novice users.

24. Validation

The tool is capable of providing a very detailed solution. The simulation of existing systems, where measurement data was available, produced results consistent with the real data.

25. Verification

The tool seemed to function as described in the documentation. Instructions detailed in the tutorial produced the desired results.

C. CONCLUSIONS

OPNET Modeler, while not for the beginner, is a comprehensive tool. It provides the user with the ability to model at the state and process level. This provides a greater flexibility in the modeling of new technologies.

OPNET is a sophisticated program for modeling and simulating communication systems, protocols, and networks. OPNET provides a friendly environment for building and analyzing communication and computer networks.

III.   COMNET III

A.   INTRODUCTION

COMNET III™ from the CACI Products Company is a network planning tool designed with an object-oriented environment to model Local Area Networks (LANs), Wide Area Networks (WANs) and Metropolitan Area Networks (MANs). The network is created graphically and requires no actual code programming by the user.

Network technologies and traffic files can be imported from various systems. Animation provides the user with the ability to monitor the flow of the network. Building blocks, objects a user is familiar with, which include computer nodes, routers and links, may be edited to define specific characteristics of a network.

The basic steps to build a model using COMNET III are define the topology, and establish traffic and computer loads. The network is then verified for correctness and run. The game clock and the run duration can easily be altered by the user. Reports, selected by the user, are automatically generated during the run.

COMNET III allows the user to (CACI, 1997):

- Predict end-to-end delays, throughputs, and utilization of links, buffers and processors
- Reproduce random and bursty traffic patterns
- See peaks and valleys of traffic not just snapshots and averages
- Pinpoint sources of delays and bottlenecks.

The following information is gathered from the CACI Products Company's world wide web page, COMNET III Tutorial (Sullivan, 1996), and telephone interviews with the sales and support offices.

B.   ASSESSMENT CRITERIA

1.   Accessibility

COMNET III software currently is available for Windows 95, Windows NT, all major UNIX computers, Silicon Graphics Inc., AIX, Solaris, Digital Equipment Corporation, and Hewlett Packard UX. The software package is 20 megabytes (MB) for

13

the UNIX or personal computer (PC) platforms. It also requires 64 MB of remote access memory (RAM) for the UNIX and 32 MB for the PC.

2.   Completeness

COMNET III uses nodes and links as the primary model building devices. Processor nodes model communication processing devices through time delays simulating the execution of software applications and the processing of packets. Processor nodes simulate file read and writes and application runs through time delays and "Wait For" commands.

Router nodes model routers, bridges, switches, hubs, and other devices that have a common backplane for moving packets between port buffers.

Switch nodes model switches, routers, hubs, and other communication devices that have insignificant packet moving delays.

The following links can be modeled by COMNET III (CACI, 1997, pp. "A Quick Look At COMNET III"):

- Aloha
- CSMA
- FDDI
- Priority FDDI
- Polling
- DAMA
- Point-to-Point
- Token Ring
- CSMA/CA
- Token Passing
- CSMA/CD

The Point-to-Point links include ISDN and SONET libraries.

WANs and LANs are easily modeled through use of subnets and WAN cloud icons. These provide the user with various views of the network hierarchy. WAN clouds can be used to model frame relay, cell relay (ATM), and packet switching (X.25).

Inter-machine communications can be modeled if the user knows the parameters of the interface. COMNET III does not model communication system networks.

COMNET III currently does not model any military specific equipment.

3.   Configuration Management

CACI Products Company began developing simulations over 35 years ago. COMNET III is only a few years old but is widely used throughout the civilian community. COMNET III is currently on Version 1.3. It is configured as a proprietary execution environment.

14

Users are responsible for managing traffic input and data output. Output files will be overwritten during a re-run of a modified model. The entire network is displayed for the user. Details of individual nodes can be accessed and parts of the network can be "hidden" via COMNET WAN Clouds and Transit Nets. COMNET WAN Clouds and Transit Nets are icons which represent portions of the entire network to reduce the clutter on the display.

4. Cost

COMNET III is $48,500.00 for the commercial version, $2,000.00 for a single user university edition, and $3,000.00 for a university department edition. Training costs, and maintenance and upgrade costs for the first year are included. Afterwards, the yearly commercial maintenance and upgrade fee is $5,100.00 and the university fee is $500.00.

Additional packages, COMNET Baseliner and the COMNET Advance Features Package, are $9,000.00 each.

5. Data Input Methods

Users can create discrete data and continuous random variable data through tables. The discrete data is based on inputs from the user and a step distribution. The continuous data is based on a user selected probability distribution function. COMNET III, also, features source objects: Traffic, Message, Response, and Session. Traffic Source is used to model a single traffic command. Message Source works with a transport command and models protocol-control messages. Response Sources generate replies or acknowledgments; and Session Sources are for modeling multiple message, bursts, or virtual circuit routed messages.

Traffic and network topologies can be modeled through external sources. TRAFLINK, a CACI utility, reads external traffic files and formats them for COMNET III usage. Network topologies can be extracted from Network Management Systems. Third party software, Cabletron Spectrum topology files, HP Open View topology files, and IBM Net View 6000 topology files, can extract an existing network's topology to be imported into COMNET. (CACI Products Company, 1995, pp. 210)

15

6.   Data Reduction

COMNET III provides immediate graphs and reports. A Report Menu allows the user to turn on and off various reports and statistics for specific items (nodes, links, WAN clouds, application sources, message and response sources, session sources, transport commands, and setup commands). Upon completion of the run the user can immediately "browse" the results.

The following probability distributions are available in COMNET III:

- Beta
- Erlang
- Exponential
- Gamma

- Geometric
- Hyper exponential
- Log normal
- Normal

- Poisson
- Triangular
- Uniform
- Weibull

Each of these is available via a drop down menu in the parameters windows.

7.   Documentation

COMNET III's documentation consisted of one book. It is oriented towards the network manager. It does a great job of explaining the functions and capabilities of COMNET III. However, it does not describe how to use COMNET III. It is left up to the user to learn how to use the product.

A tutorial (Sullivan, 1996) was developed by a third party. It provides step-by-step instructions on how to use the major features of COMNET III.

The lack of documentation did not hamper the author's ability to quickly learn and use the basic features of the product. The menus and icons provide the user with an extremely user friendly flow for developing a model.

8.   Ease Of Use

The product is very easy to use. Network topologies are quickly developed using drag and drop icons and a menu driven environment. Parameters are altered by double clicking on the various network objects. Menu options enable the user to alter the game clock speed, animate the run, trace the run events, and run iterative trials. Results are easy to view via the "Browse" option in the reports menu. The network set up time is primarily restricted by the network knowledge of the user.

The personnel at CACI Products Company were friendly and eager to assist. The CACI world wide web page (CACI, 1997, pp. "COMNET Support") provides helpful email addresses and phone numbers. COMNET III and generic modeling questions can be answered via a customer hotline provided to valid users. Additional modeling assistance is available at a cost from the CACI Modeling Group.

The product is very easy to learn. The thesis tutorial developed by Jeffrey Sullivan (Sullivan, 1996) provides a quick overview of all of the basic COMNET III features.

The run times of this product vary with the detail of the simulation. The simple networks designs, created using the tutorial, executed in only a few minutes. A detailed 10,000 node network with multiple events and detailed parameters would take much longer.

9. Experimental Design

The modeling tool provides the user with the ability to execute trials iteratively during a single run. Additionally, the automatic parameter feature enables the user to vary the parameters during the iterative executions. This provides the user with a faster method for evaluating proposed network changes. The user can modify existing parameters to examine alternate computer networks, but COMNET can not model communication systems.

10. Extendibility

The program itself cannot be modified or extended. The source code is not provided to the user. COMNET III does provide the user with a high level, simple program interface. The programming is similar to Basic. It provides greater flexibility to the user. Counters and triggers can be established to initiate follow on events. An example would be when the utilization of a link is greater than 60% switch to an alternate link.

11. Extensibility Of Results

COMNET III provides the user with two primary methods for evaluating an emerging architecture. First, with the basic, high level programming option which can be used to set counters and triggers to evaluate the results of an event; second through the

17

use of transit nets. Transit nets provide a more detailed option for modeling transport protocols. It enables the user to create a protocol like frame relay via an ATM link.

COMNET III does not specifically model data channels or software applications.

12. Fidelity

The tool reliably provides results consistent with the input parameters. COMNET Baseliner, an add on feature, enables the user to model existing networks with realistic external data. The detail of the model can only be slightly varied.

13. Flexibility

Nodes can be set up to start, stop, or model a delay during the execution. Parameters can be easily altered by double clicking on the items icon.

14. Interoperability

COMNET Baseliner, an add on feature, enables the user to model existing topologies and use realistic traffic files. Actually topology data can be taken via a Network Management System, like HP Open View, Network General, Cabletron Spectrum, IBM NetView for AIX, and Castlerock SNMP, and imported in COMNET. Network traffic data can be gathered from Network General Distributed Sniffer System, Frontier Software NETscout, HP NetMetrix, CompuWare EcoNET and 3COM LANsentry. This data can then be imported into COMNET III via COMNET Baseliner. This importing capability provides the user with the ability to model a current network and real data to run on it. This model can then be tested to find any network problems, evaluated for interfaces with new equipment, tweaked to find the peak performance design, etc.

A small amount of traffic gathered can be emulated to create a large database of "realistic" data. This prevents the user from having to gather hours of real data.

15. Miscellaneous

Outages can be caused or enabled through parameter settings and/or by establishing triggers and counters. Outages can be for a predefined time, simulating a nodes movement; for a random time, simulating a maintenance outage; or permanently, to simulate equipment destruction.

Frequency and terrain options are not available with COMNET III.

16. Operational Environment

This product is available for Windows 95, Windows NT, UNIX stations, SGI, AIX, Solaris, Dec, and HP UX systems. All these systems are COTs and easily obtainable to users. Portability depends on the platform the software is installed on.

17. Post Analysis Support

COMNET III provides a wide variety of reports. Each of these is available for viewing immediately after the run execution. Reports must be turned on by the user for the data to be collected. The following reports are available within COMNET III (CACI, 1997, "COMNET III Features List"):

- Node Reports: Processor and disk utilization; Received message counts; Session level; Call counts; Call level; Buffers by node; Buffers by port
- Link Reports: Channel utilization; Utilization by application; Utilization by protocol; Frame Size; Collision Statistics; Token ring statistics; Session level; Call counts; Call level
- WAN Cloud Reports: Message and Response Source Reports; Message delay; Message delivered delay; Packet delay
- Cell Source Reports: Blocked call counts; Disconnected call counts; Preempted call counts
- Transport Command Reports: Message delay; Packet delay
- Session Source Reports: Message delay; Message delivered delay; Packet delay; Setup delay; Session Length; Setup counts; Transport Layer
- Snapshot Reports Node reports; Link reports; Cloud virtual circuits
- Statistics file for export to other analysis: Real-time plots; Post-processed plots; Percentiles; Raw data plot file

18. Reliability

The product is coded primarily in a high level, icon drag and drop language. It executes in its own run time environment. Modeling errors may cause the experiment to suddenly terminate. Diagnostic information is available.

19.   Security

No security options are available.

20.   Software

CACI Products Company has been a simulation leader for 35 years. COMNET III Version 1.3 was fielded in December 1996. The source software code is unavailable to the user. The product is a drag and drop icon and menu based environment. It has a simple flow for network development. CACI distributes minor releases throughout the year and major releases periodically. Over 2000 various universities and companies are currently using COMNET III (CACI, 1997, pp. "A Quick Look at COMNET III").. COMNET III is an object-oriented software application.

21.   Training / Tutorial

CACI Products Company provides a free three day overview/orientation training to new users. Additionally, the tutorial (Sullivan, 1996) is a great beginners manual. Training is primarily at the beginner level. COMNET III is not a difficult program to learn.

22.   Troubleshooting Assistance

Animation and event tracing are available to assist the user in network flow monitoring and troubleshooting. All valid users, those having paid the yearly upgrade fee, are provided with a Customer Support Hotline. CACI, for a cost, has a Modeling Group to assist companies in developing a model for a network. Assistance is available via email and the world wide web.

23.   User Interface

The product is very user friendly. The network topology can be created via drag and drop icons or with menu options. Once the topology is established, parameters may be altered by double clicking on the items. A parameter window will appear with drop down menus to assist the user. The verify option provides a detailed list of all errors present in the network topology or basic flow.

The user may alter the run time parameters (clock speed, run iterations, animation, event trace) through a simple menu. Post analysis support allows the user to easily "browse" the reports and statistics.

24.   Validation

The simulating of existing networks where measurement data is available produced results consistent with the real data.

COMNET III provides the user with a basic to intermediate analysis of the network and its interfaces. This is dependent on the parameters and events established by the user.

25.   Verification

Upon completion of the model, the product does a quick verification of the network connections.

The tool seemed to function as described in the documentation. Instructions detailed in the tutorial produced the desired results.

C.   CONCLUSIONS

COMNET III is a simple, straightforward, comprehensive network planning tool. User training is easy, and icon-based network designing allows for quick construction and reconfiguration. COMNET III provides a method for analyzing and optimizing computer-based networks.

IV.   EXTEND

A.   INTRODUCTION

Extend, developed by Imagine That Inc., is an advanced simulation tool designed to develop dynamic models of real-life processes. It enables the user to: predict the course and results of certain actions; understand why observed events occur; identify problem areas before implementation; explore the effects of modifications; confirm that all variables are known; evaluate ideas and identify ineffectiveness; gain insight and stimulate creative thinking; and communicate the integrity and feasibility of plans (Imagine That Inc., 1995, pp. 4).

B.   ASSESSMENT CRITERIA

1.   Accessibility

Extend is available for Windows 3.1 or later, Windows 95, Windows NT, Macintosh 6.7 or later, and Power Macintosh System 7. 10 MB of hard disk space are required for the Windows version and 8 MB of hard disk space are required for the Macintosh version. Both platforms require 4 MB of RAM but 8 MB are recommended.

Models built on either platform can be run on the other platform. For example, if you build a model or library on a Macintosh computer, it can easily be read on a Windows computer.

2.   Completeness

Extend uses icons or building blocks to build models. 15 libraries of various building blocks are included with Extend. The building blocks represent the smallest level or function of a model. The user must build computers, communications equipment, systems, etc. from the basic functions and flows. This requires the user to be proficient in modeling.

Users can create new icons which can be saved in the libraries. They can also save models as templates to be used in other models. This provides the user with the power to create the computers and equipment to be reused in later models. Additionally, a list of libraries available through third parties is available through Imagine That, Inc.

3. Configuration Management

Imagine That Inc. was founded in 1987 to market Extend software. Extend is current on version 3.2.

The user is responsible for managing input and output. Extend permits hierarchical modeling. The user via levels (subroutines) can make a complex system easy to build and easy to understand.

4. Cost

Extend is available for $695.00. The university price is $350.00. Technical support is free provided the user has purchased the most recent upgrade version. Today's current upgrade from version 3.1 to version 3.2 is $99.00.

Imagine That Inc. does not offer any in house training programs.

5. Data Input Methods

Extend includes an input random number menu, and an input data menu. The first provides the user with a distribution selection, and the latter permits the user to enter specific data values.

Extend uses text files for importing and exporting data. Text files can be created in another application, like a spreadsheet, word processor or database, then read into Extend, and vice versa. This is easier for inputting lists of files and for manipulating simulation results.

6. Data Reduction

Plotters are built into the model to gather statistics. Results of the plotters can be immediately displayed on the screen.

The following are available to gather statistical information from the results: D-Binomial, D-Exponential, D-Gamma, D-Log Normal, D-Pascal, D-Poisson, Gaussian, Mean, Random, Random Get Seed, Random Real, Random Set Seed, Standard Deviation Population, Standard Deviation Sample, Statistical Value. (Imagine That, Inc., 1995, pp. 287)

7. Documentation

Extend has one book for its documentation (Imagine That, Inc., 1995). It is very comprehensive. Chapters 1 through 3 consist of a tutorial of Extend's basic features. Chapter 4 is an overview of continuous and discrete modeling. Chapter 5 discusses all of Extend's libraries. Chapter 6 describes the methods to get data into and out of Extend. The rest of the book provides a more in depth look at Extend, modeling, how to build icons, and a list of common errors and their causes.

8. Ease Of Use

Extend is fairly easy to use. Models are constructed with building blocks via windows and menus. Double clicking on a building block provides access to the items attributes.

Extend's biggest challenge is the user must know the intricate details of the system or equipment to correctly model the functions and flow.

Set up time is dependent on the depth of the model. The basic examples provided in the tutorial took about 15 minutes to create and only a few minutes to run.

Extend allows the user to vary the run time, and the step speed or clock speed. The user can, also, vary the model while it is running online.

9. Experimental Design

Extend supports Monte Carlo and batch mode simulations. Iterative runs can be conducted. The plotters will only maintain the most recent four plots. Extend's basic features enable the user to model emerging systems.

10. Extendibility

Extend primarily uses icons or building blocks to construct models. Extend's source code is the ModL language. It is based on the language C.

Extend permits the user to create their own building blocks or modify existing ones. The user can use "scripting" to design code for the model.

11.   Extensibility Of Results

Extend allows the user to create building blocks. These can be used to create virtually any communication or computer system.. Extend's extensibility is limited to the modeling and programming capabilities of the user.

12.   Fidelity

The tool reliably provides results consistent with the input parameters and the model. The user's ability to create building blocks could effect the behavior of the model. Models can be developed with various degrees of detail.

13.   Flexibility

Extend provides the ability to alter the model both on and off line. The user can simulate the time lost for the movement of a node or for maintenance down time through the use of time delays, blocks, and triggers.

14.   Interoperability

Extend has cross-platform capabilities between Windows and Macintosh. Extend allows users to copy data from text entry fields and data tables into other applications.

Extend permits the user to create building blocks to communicate with scientific equipment and other hardware devices. Extend, also, provides two methods for accessing code written in another language: XCMD (for Macintosh) and DLL (for Windows).

15.   Miscellaneous

Outages can be caused or enabled through delays, triggers and blocks. Outages can be for a predefined time, simulating a nodes movement; for a random time, simulating a maintenance outage; or permanently, to simulate equipment destruction.

Frequency and terrain options are not available with Extend.

16.   Operational Environment

This product is available for Windows and Macintosh systems. All of these systems are COTs and easily obtainable to users. Desktop and notebook computers are both very portable.

17.   Post Analysis Support

Extend has a wide variety of plotters available to display output: Discrete Event (DE) Error Bars; DE Multi-Simulation; DE; Error Bars; Fast Fourier Transform; Input/Output; Multi-Simulation; Histogram; Scatter; Scatter (4); Strip; and the Worm.

The user can, also, select blocks to record data from for a report. These reports only display final simulation values.

18.   Reliability

Repeated runs of models based on constant inputs produce the same results. Extend executes in its own run time environment.

19.   Security

No security features are available.

20.   Software

Imagine That Inc. developed Extend in 1987. Extend is written in ModL, a C based language. The user creates models by connecting building blocks to simulate the basic functions and flows of the system.

21.   Training / Tutorial

Imagine That Inc. does not offer any in house training courses. There are some third party training courses available for a cost.

The first three chapters of the Extend users manual are a comprehensive tutorial. They provide the user with a complete overview of Extend's major features.

22.   Troubleshooting Assistance

Animation and event tracing are available to assist the user in network flow monitoring and troubleshooting. Common error messages and their causes are listed in an appendix.

Extend provides phone, email, fax, and world wide web technical assistance. Free technical assistance is available to all users modeling with the latest Extend upgrade.

### 23.	User Interface

The product is very user friendly. Extend's user interface is through building blocks and menus. The user can quickly and easily build a model by selecting building blocks from the menu of libraries, and then connecting the blocks together.

### 24.	Validation

Extend's degree of accuracy is based on the users design. A properly designed model produces realistic results.

The user creates the model to the depth of answer required.

### 25.	Verification

Extend will verify the basics of the code during compilation.

The tool seemed to function as described in the documentation. Instructions detailed in the tutorial produced the desired results.

## C.	CONCLUSIONS

The program Extend is not difficult to learn. The user must be able to model the basic functions and flows of each element and combine them to build the model.

Due to Extend's purpose of modeling real life processing in a wide variety of areas, many of its features are generic and not communication and computer specific. This does not restrict the program's ability to model communication and computer networks but instead expands the user's modeling options.

V. WORKBENCH

A. INTRODUCTION

Workbench developed by Scientific and Engineering Software, Inc. (SES) is a general purpose modulation and simulation tool. Workbench is a collection of software tools used to design and evaluate sophisticated systems of various types. It's major components are: SES/*design* ™, a graphical editor; SES/*sim*, a translation and simulation module; and SES/*scope*, an animated simulator.

Workbench is an object-oriented product. Models are built with a top down construction, beginning with the catalog level, then the module and sub-module levels.

Workbench is designed to model the essential characteristics of a system, while ignoring the unimportant details. It focuses on the high-level system architectural issues.

B. ASSESSMENT CRITERIA

1. Accessibility

Workbench is available for the Sun, IBM, and Hewlett Packard UNIX platforms.

2. Completeness

Workbench consists of a variety of module and sub-module building blocks/icons. These building blocks can be used to create models of current and future computers, software, and communications equipment. The models are constructed by connecting the build blocks or nodes with arcs. Workbench permits the user to create icons. These icons must be based on a basic building block but can be stored in a library for future usage.

The basic building blocks or the icon palettes for Workbench are: Resource Management Nodes: service, delay, resource, allocate, release, create, destroy, block and set; Transaction Flow Nodes: source, sink, fork, join, split, loop, interrupt, resume, and branch; Sub-Module Management Nodes: enter, call, sub-model, and return; and Miscellaneous Nodes: user, declaration, and super. The catalog level provides the user with these building blocks: main module, generic module, remote module, interface module, object file, cosim interface, archive file, user make rules, remote catalog and a palette icon.

29

Once a module is built it can be archived for use in future models. This enables the user to create a library of frequently used items.

Workbench includes a variety of queuing rules. These include priority rules which allow no priority, preemptive, and non-preemptive priorities. The time rules include: first come, first served; last come, last served preemptive resume; processor sharing, and round robin.

3.   Configuration Management

SES, founded in 1971, has evolved from a consulting and research organization to a global software and consulting firm. For more than 25 years SES has been providing simulation technology to its customers.

The user is responsible for managing input and output files. User's can specify which nodes to gather statistics. A rerun will overwrite previous output files.

A user can view the modules and sub-modules developed during the building of the model. The main module is typically designed to be a complete diagram of the network or system being modeled.

4.   Cost

A SES sales representative will help design a software package of Workbench and its associated files to meet the users needs. Workbench's starting commercial price is $23,500.00. The university price is $500.00. The government price is 20% of the cost of the civilian priced package. Technical support and upgrade costs are 15% of the original package price.

Training is available at SES Regional Sites for $8,000.00 per person. This is for the three day introductory course.

The Network Framework Library, consisting of: X.25, TCP, ATM, FDDI, SNA, Client/Server and Ethernet, can be purchased for $5,000.00 (civilian price). SES, also, has a huge list of partially developed models. These models are free and can be requested as needed.

5.   Data Input Methods

Users can input data internally via tables. External interfaces include: C and C++ programs and Objectbench files. The users must establish the link or interface between Workbench and the external functions.

6.   Data Reduction

Workbench provides immediate access to statistics gathered during a simulation run. The user can select global or specific statistics to be gathered. The standard statistics that Workbench gathers are: inter-arrival, lifetime, population, q-population, q-response, quantity, response, and utilization. Users can, also, create user-defined "collect" statements in C language to accumulate additional continuous or discrete statistics not ordinarily collected by Workbench.

Workbench includes these probability distributions: empirical, erlang, exponential, gamma, hyper-exponential, normal, triangular, uniform, binomial, geometric, I-empirial, I-uniform, and poisson.

7.   Documentation

Workbench's documentation is quite extensive. The Quick Start Manual provides a basic overview of the most commonly used features and includes an example or mini tutorial on creating, compiling and animating a simple model. Creating Models, Simulating Models, SES/*sim* Language Reference, Technical Reference, Query Interpreter and Language Reference, Cosim Reference, and an Installation Manual are, also, included in the Workbench documentation.

No design specifications were available.

8.   Ease Of Use

The basic features of Workbench are fairly easy to learn and use. Menus and icons create a user friendly environment that provides the user with a graphical interface to modeling. Workbench, however, is not designed to model any specific type of network. It is a general modeling tool. What this means is the libraries and icons have basic low level functions. The user must create anything specific needed for the model. The user needs to be a proficient modeler to get the maximum usage of this software.

Workbench uses a top down modeling approach. The user establishes a catalog with a main module and possibly some other generic modules. Each module is then developed further as a sub-module. The user can "travel" back and forth between the levels of the modules and sub-modules. This level approach allows the user to break the model down into small manageable pieces.

The user manuals are easy to follow. There is an index in the back of each book of the documentation. The index provides a quick reference to all of the documentation manuals. The manuals provide details and execution steps for most of the topics.

Once again run time and set up time are dependent on the detail of the model. The user must design the model to the accuracy desired in the solution. Workbench uses multithread processing to simulate numerous events occurring simultaneously. The run length and run interval time or clock speed, can be altered prior to the execution of the simulation.

9. Experimental Design

Workbench does not offer an iterative run capability. Workbench's basic features, modeling with sub-modules, enables the user to model emerging system by breaking them down into their smallest elements.

10. Extendibility

Workbench uses a C based language. Users can add C language procedures to be included in the simulation program. These additions enable Workbench to be extended as necessary. The user can access the code developed for the model.

11. Extensibility Of Results

The ability of the user to add C programming statements, also, enables the user to create new and alternative computers, communication equipment and any other type of system. This capability is limited by the user's ability to program in C language.

SES offers, for a price, extension products.

12. Fidelity

This product seems to provide realistic results consistent with the input parameters and model. However, Workbench is graph-oriented programming, which is

dependent on user definitions for its behavior. Models can be developed with various levels of detail.

13.   Flexibility

Nodes can be delayed or blocked, simulating movement or destruction, through a time activation, probability distribution, or a trigger. Each of these must be created as part of the model.

14.   Interoperability

Workbench can interoperate with most programs created in C. C programs can be imported into the model and run as part of the simulation.

15.   Miscellaneous

Workbench does not offer any terrain or frequency features.

Outages must be developed as part of the model. Delays and blocks can simulate temporary and permanent outages. Time delays, probability distributions and triggers can be established to create and fix outages.

16.   Operational Environment

Workbench is only available for UNIX platforms, and thus are not very portable. The platforms are commercially available.

17.   Post Analysis Support

Workbench provides textual reports and machine readable output. The reports can be displayed on the screen or printed. The reports consist of: a cover page, two optional user-generated output sections, a report header, a detailed statistical report, an optional node summary statistical report, and an ending banner. The machine readable output can be post processed using most commercial spreadsheets or word processors. The user can, also, print the graphical representation of the model.

Available only on SUN platforms, SES/*graph* is a small easy to use graph program. It is a front end for a program called *grafit* [R] created by Graphicus, Inc., Kirkland, Washington. (SES, 1994-1995, pp. A-1). SES/*graph* enables the user to display and plot statistical data produced during the model's run. These graphs can be displayed in bar charts, pie charts, line charts, spline charts, or a step function chart.

18. Reliability

The product executes in its own run time environment. Debugging features are included.

19. Security

Workbench does not offer any security features.

20. Software

Workbench is based on the C language. Workbench uses an object-oriented environment. The user can access and alter the code developed for the model.

21. Training / Tutorial

Workbench training is available at SES Regional Sites. Customized training can be requested, for a cost, to be conducted at the user's site. Introductory and advance classes are available.

Workbench's documentation includes a basic tutorial. It is a quick overview of the program's primary features.

22. Troubleshooting Assistance

Workbench has animation and trace capabilities. The user can view the code by accessing the model's file.

SES offers assistance via a 1-800 telephone number, email, the world wide web, and through regional sites. Frequently asked questions are available through the world wide web to registered users.

23. User Interface

The user interface is graphic oriented. The user through menus, icons, and arcs or connection tools, creates a graphic picture of the model. The flow of the menus can be confusing to the novice user. The user can modify the parameters of the nodes and can add C programming to augment the simulation.

24. Validation

Workbench provides the user with the option of modeling to the small details or on a larger scale. Models programmed via code will depend on the users modeling ability for validity.

25. Verification

No verification features were identified. The product seems to function as described in the manual.

C. CONCLUSIONS

The basic commands for Workbench are easy to learn. Workbench requires the user to be a proficient modeler. The user must be able to understand the basic functions of the system they are modeling. Workbench, also, places heavy emphasis on understanding programming. Workbench is a good tool, however, it is not designed for the beginner.

VI.   G2

A.   INTRODUCTION

G2, from the Gensym Corporation, is designed for developing intelligent, knowledge-based, real-time applications. G2 is typically utilized for complex situations that require: monitoring, diagnosis, and alarm handling; scheduling and logistics; supervisory and advanced control; process design, simulation, and re-engineering; intelligent network management; and decision support for enterprise-wide operations (Gensym, 1995, pp. 4).

Each intelligent application developed or modeled is known as a knowledge base (KB). KBs are developed in a graphical and menu oriented environment using Object Oriented Modeling. Gensym Corporation uses Object Oriented Modeling as the bases of the G2 product.

B.   ASSESSMENT CRITERIA

1.   Accessibility

G2 can be installed on UNIX, VMS, Windows 95, and Windows NT platforms. These include Digital Equipment Corporation, Hewlett Packard, Sun SPARC stations, Silicon Graphics, and IBM Reduced Instruction Set Computers. G2 requires 30 MB of hard disk space and 48 MB of RAM.

2.   Completeness

G2 enables the user to model computers, software, and communication equipment through the use of Object Oriented Modeling. Specific KBs must be developed by the user.

G2 provides the modeler with the capabilities to create not only the model but the interface that the operator will have with the simulation. The operator can be prompted for input via toggle switches, text inputs, or interactive buttons. The modeler can create an interactive on-line simulation environment.

The Army Artificial Intelligence Center is currently using G2.

3. Configuration Management

Gensym Corporation was founded in 1986. Gensym Corporation currently provides services to over 30 countries which include petroleum companies, chemical companies and other industrial companies.

The user is responsible for managing input and output files. G2 graphically shows the objects within the designed system. Data encapsulation or hiding is available to reduce clutter and access to some information. Object relationships can be depicted by showing the workspace module hierarchy.

4. Cost

The current commercial cost for the G2 server license with Telewindows is $36,000.00. A minimum of one user license must be purchased at $4,800.00 (User license prices decrease after the eleventh user). The university cost is $500.00. The GSA cost is 31% of the commercial cost.

Customer service support is available for a yearly fee of 15% of the commercial list price ($6,120.00 for a single user package).

Free one and one half day workshops are available at select regional sites. G2 Part I and Part II training, each a four and one half day course, is available for $2,295.00 each.

5. Data Input Methods

G2 includes internal and external data source, or data server, features. G2's internal data servers are the G2 inference engine and the G2 simulator. The G2 inference engine "concludes" or calculates an answer from specific formula objects. The G2 simulator receives a value from a simulation formula.

External data server methods include data received from other G2 processes, from GFI bridge applications, and from GFI files. (See Interoperability sub-section for more information)

6. Data Reduction

G2 does not offer any standard statistical features.

7. Documentation

G2 provides a complex assortment of documentation. The titles of the manuals are very misleading as to the content to a beginning user. These manuals include: *G2 Reference Manual, Upgrading Your Knowledge Bases, G2 Systems Procedures Reference Manual, Telewindows User's Guide* ,and *G2 GUIDE User's Guide*. G2 documentation is very complicated. It is oriented toward a proficient object oriented modeler.

G2 does not offer any tutorial.

Design and modeling documentation is not available.

8. Ease Of Use

G2 is not easy to learn. It is entirely object oriented. Existing KBs are not labeled well enough to know what they contain. The user can create KBs of computers and communication equipment and save them for reuse.

The manuals provide guidance on the G2 functions and features but do not cover any Object Oriented Modeling.

Set up time is dependent on the detail of the model, the related KBs available to build upon, and the users ability to use object oriented analysis and design.

G2 has three options for running a simulation: real time, simulated time, and as fast as possible. The model and the inputs can be altered while the simulation is running.

9. Experimental Design

G2 does not offer any iterative run capabilities. Object oriented modeling enables the user to create objects and attributes to model emerging systems.

10. Extendibility

G2 models can be altered on line or off line. G2 uses a structured natural language, similar to COBOL. The language uses ordinary human statements, so the user does not need to be a proficient programmer. G2's natural language, also, supports Japanese, Korean, and Russian.

A text editor is available for the user to input specific statements, rules, functions, attributes, etc.

11. Extensibility Of Results

G2 and Object Orient Modeling provide the user with a flexible environment capable of modeling virtually any computer or communication system the user can imagine. The product is limited by the users ability to analyze and design a model..

12. Fidelity

The tool reliably provides results consistent with the input parameters. Models can be developed with various degrees of detail.

13. Flexibility

Nodes can be moved both on and off-line. The user can establish time delays, triggers or interactive inputs to initiate the move or outage.

14. Interoperability

G2 provides networking and interfacing through Telewindows, G2 to G2 Interface, G2 Standard Interface (GSI), and G2 File Interface(GFI). Telewindows allows more than one user to access, or remote view, a running G2 process. G2 to G2 Interface lets two or more G2 process to connect to share data. GSI is a toolkit for developing bridges between G2 and external systems. GFI allows G2 to read and write external data files.

15. Miscellaneous

Outages can be simulated with time delays, triggers, or interactive input by the operator.

Frequency and terrain options are not available with G2.

16. Operational Environment

This product is available for UNIX, VMS, and Windows platforms. All these systems are COTs and easily obtainable to users. Portability depends on the platform the software is installed on.

17. Post Analysis Support

G2 features include readout tables, dials, meters, freeform tables, charts, graphs and trend charts. Readout tables, dials and meters depict changing values during a simulation run. Freeform tables are similar to spreadsheets. Charts plot numerical data

series. Charts include data points, bar charts and column charts. Graphs are being replaced by trend charts. Trend charts plot times series and historical data.

18.   Reliability

The product executes in its own run time environment. Results are consistent with the inputted model.

19.   Security

G2 provides network security features. These features include: connect, read, write, execute, and inform. Connect prohibits or enables other users from accessing a KB. Read and write prohibit or enable other users from reading or writing variable values. The execute command deals with remote procedure calls, and the inform command prohibits or enables other users from sending messages to the operator.

20.   Software

G2's structured natural language provides the modeler with a user friendly program interface. The modeler can use ordinary human language statements to input specific commands for the model to execute. G2's language and modeling environment are object oriented.

21.   Training / Tutorial

G2 offers numerous training courses: Introduction, G2 Part I, G2 Part II, and many classes for supporting products. Courses provide a wide variety of information on how to use G2. The combine syllabus for the Introduction, and G2 Parts I and II indicates that upon completion of the training the user will have an intermediate knowledge of the product.

No tutorial is available. Some demonstration KBs are included.

22.   Troubleshooting Assistance

G2 has been rated number one in customer support by Control Magazine for the last two years (Gensym, 1997, pp. "Services"). Engineers are available, by telephone, Monday through Friday, to assist with installation, product use, problem diagnosis, and configuration questions.

G2 Help Link is a 24 hours a day, seven days a week, automated help service available through the G2 world wide web home page. The Gensym Users Society (GUS) provides technical communications between Gensym customers and the Gensym Corporation. Help services are, also, available through email.

Animation is not available.

23. User Interface

The G2 user interface is menu oriented. The number of menus can be overwhelming to the beginning user. Menus lead to construction of objects, classes, connections, etc. Once an item is created, it is defined through a table. Most table entries are prompted with a list of available options. Some entries allow the user to provide input into the model. For example: variable and object names, or the use of structured natural language to input exact specifications for an object.

24. Validation

Users can model to the depth desired. The user must use correct object oriented analysis to properly define the system to be modeled.

25. Verification

The product functioned as described in the manuals. Gensym Corporation has sold more than 7500 product licenses to over 500 organizations worldwide (Gensym, 1997, pp. "Company").

C. CONCLUSIONS

G2 is based on object oriented analysis and design. "Object oriented analysis is based upon concepts that we first learned in kindergarten: objects and attributes, classes and members, wholes and parts." (Pressman, 1992, pp. 239)

The product, while initially intimidating, is a very powerful tool. The structured natural language enables a non-programmer to have the features and capabilities available to create a detailed model of a complex system.

VII. ANALYSIS

A. INTRODUCTION

This section compares the five software products. A rating of 1 to 5 has been established for each evaluation criteria based on the sub-criteria contained in the Appendix:

    1 - no sub-criteria satisfied

    2 - less than half of the sub-criteria satisfied

    3 - half of the sub-criteria satisfied

    4 - more than half of the sub-criteria satisfied

    5 - all of the sub-criteria satisfied.

Additionally, general usage, vendor, available platforms and the average price have been included.

B. COMPARISON

Table 7-1 shows a non-weighted comparison of the software products.

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
General Usage	Comm Networks, Computer Systems and Applications, and Distributed Systems	Network Planning Tool, LAN/WAN	Simulation Tool	System Level Simulation Tool	Intelligent Real Time Systems
Vendor	MIL 3 Inc.	CACI Products Company	Imagine That, Inc.	SES	Gensym Corp.
Platforms	Sun SPARC, DEC, HP UX, SGI, Windows NT	PCs (Windows NT and Windows 95), UNIX, DEC, HP UX, SGI, AIX, Solaris	PCs (Windows 3.1, NT and Windows 95), Macintosh	Sun Micro-stations, IBM, HP	Digital, IBM, HP, Sun Micro-stations, PC's (Windows NT and Windows 95)
Price Commercial University	$18,000.00 $600.00	$48,500.00 $3000.00	$695.00 $350.00	$23,500.00+ $500.00	$40,800.00 $500.00
Accessibility	3	3	3	2	3
Completeness	5	3	4	4	4
Configuration Management	5	4	4	5	5
Cost	4	1	5	3	2

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
Data Input Methods	5	5	5	5	5
Data Reduction	5	5	5	5	3
Documentation	4	3	3	4	3
Ease Of Use	3	4	3	3	2
Experimental Design	4	2	5	3	3
Extendibility	4	2	4	5	5
Extensibility Of Results	5	2	4	4	4
Fidelity	5	4	5	5	5
Flexibility	4	4	4	4	4
Interoperability	4	2	4	4	4
Miscellaneous	4	2	2	2	2
Operational Environment	5	5	5	3	5
Post Analysis Support	5	5	3	4	5
Reliability	5	5	5	5	5
Security	3	1	1	1	3
Software	3	3	3	4	4
Training / Tutorial	4	4	4	3	2
Troubleshooting Assistance	3	3	4	5	3
User Interface	4	5	5	4	4
Validation	5	5	5	5	5
Verification	5	5	5	5	5
Non Weighted Totals	106	87	100	97	95

Table 7-1. Comparison of Products.

C.   THE GRAND SOLUTION

A quick total suggests that OPNET is the best overall software product. However, the criteria must be weighted when selecting a specific software product for the user's needs.

By weighting each evaluation criterion, a priority for the characteristics required for a mission is established. These weights may differ for each distinct task. An organization should give serious consideration to the weights based on their generic usage of the product (unless the organization can afford to purchase more than one product).

This will provide the organization with a product that may not be the "best" for every instance, but will be the "best" for the organization's overall usage.

An example, a unit is looking for a software product that can model experimental architectures and systems in addition to communication and computer networks. The unit has no UNIX machines, mostly PCs, and a few Macintoshes. The operators are proficient in C Language, but troubleshooting assistance and user interface are considered key for the experimental design of the system. Frequency and terrain have no bearing on the systems to be modeled. Minimizing cost is very important to the unit. The unit may establish the following weights: Completeness - 1, Cost - 5, Experimental Design - 5, Extendibility - 4, Miscellaneous - 1, Security - 1, Software - 5, Troubleshooting Assistance - 5, User Interface - 5, and all other criteria may be a 3. Each weight is then multiplied by the product's score to produce a weighted score. The weighted scores are totaled. The product with the highest weighted score is the best modulation simulator based on the current priorities. In this example that would be Extend. Table 7-2 depicts the comparison example with weighted scores.

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
General Use	5*3 = 15	5*1 = 5	5*4 = 20	5*4 = 20	5*4 = 20
Platform	4*4 = 16	4*4 = 16	4*5 = 20	4*1 = 4	4*4 = 16
Accessibility	3*3 = 9	3*3 = 9	3*3 = 9	3*2 = 6	3*3 = 9
Completeness	1*5 = 5	1*3 = 3	1*4 = 4	1*4 = 4	1*4 = 4
Configuration Management	3*5 = 15	3*4 = 12	3*4 = 12	3*5 = 15	3*5 = 15
Cost	5*4 = 20	5*1 = 5	5*5 = 25	5*3 = 15	5*2 = 10
Data Input Methods	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15
Data Reduction	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15	3*3 = 9
Documentation	3*4 = 12	3*3 = 9	3*3 = 9	3*4 = 12	3*3 = 9
Ease Of Use	3*3 = 9	3*4 = 12	3*3 = 9	3*3 = 9	3*2 =6
Experimental Design	5*4 =20	5*2 = 10	5*5 =25	5*3 =15	5*3 = 15
Extendibility	4*4 = 16	4*2 = 8	4*4 = 16	4*5 = 20	4*5 = 20
Extensibility Of Results	3*5 = 15	3*2 = 6	3*4 = 12	3*4 = 12	3*4 =12
Fidelity	3*5 = 15	3*4 = 12	3*5 = 15	3*5 = 15	3*5 = 15
Flexibility	5*4 = 20	5*4 = 20	5*4 = 20	5*4 = 20	5*4 = 20
Interoperability	2*4 = 8	2*2 = 4	2*4 = 8	2*4 = 8	2*4 = 8
Miscellaneous	1*4 = 4	1*2 = 2	1*2 = 2	1*2 = 2	1*2 = 2
Operational Environment	3*5 = 15	3*5 = 15	3*5 = 15	3*3 = 9	3*5 = 15

	OPNET MODELER	COMNET III	EXTEND	WORKBENCH	G2
Post Analysis Support	3*5 = 15	3*5 = 15	3*3 = 9	3*4 = 12	3*5 = 15
Reliability	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15
Security	1*3 = 3	1*1 = 1	1*1 = 1	1*1 = 1	1*3 = 3
Software	5*3 = 15	5*3 = 15	5*3 = 15	5*4 = 20	5*4 = 20
Training / Tutorial	3*4 = 12	3*4 = 12	3*4 = 12	3*3 = 9	3*2 = 6
Troubleshooting Assistance	5*3 = 15	5*3 = 15	5*4 = 20	5*5 = 25	5*3 = 15
User Interface	5*4 = 20	5*5 = 25	5*5 = 25	5*4 = 20	5*4 = 20
Validation	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15
Verification	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15	3*5 = 15
Non Weighted Totals	369	306	378	348	344

Table 7-2. Example Weighted Comparison of Products.

D.   OVERALL COMPARISON

Each of the five products analyzed in this thesis has its own special characteristics and capabilities. Why select one over the other? The functions and capabilities vary making some products more preferable for different applications and scenarios.

CACI's COMNET III is the best choice for modeling a WAN or LAN. COMNET III provides all the familiar computer network icons in a user friendly environment to enable the user to quickly model and analyze a computer network. COMNET III, however, does not model communication or information systems. Nor does COMNET III model the innards of a computer.

MIL 3 developed OPNET Modeler which can model computers, communication and information systems from the network through the process and state levels. Numerous libraries are available to assist the modeler. OPNET's primary disadvantage is its fixed run speed. This can cause extensive time delays during a simulation run of a detailed model.

SES' Workbench, like OPNET, can be used to model communication, computer, and information systems. In addition, Workbench can be used to model numerous other types of systems, to include queues, electric flow, water pollution, etc.. The ability to model more than just communication, computer and information systems provides an added flexibility to the modeler.

Extend, developed by Imagine That Inc., is similar in its capabilities to Workbench, in that it can, also, model any type of system. Extend, however, provides a more user friendly environment for the modeler. Besides the documentation's ease of use, the menu setup has a more logical flow. Workbench, through the use of sub-modules, can model to a smaller level of detail than Extend, and Workbench can handle larger sized models.

G2, also similar to Workbench in its system modeling capabilities, is in a class by itself. G2 utilizes an object oriented modeling environment with a structured natural language. This product is a great selection for a beginner or non-programmer. Object oriented modeling enables the modeler to design the level of fidelity and complexity to be modeled. G2 includes a wide range of knowledge bases or libraries, though the labeling is puzzling. G2/object oriented modeling is not an easy product/modeling method to learn.

It is essential to look at the capabilities and characteristics of the modeler(s). Programming skills can influence the product selection. All five of the products are icon and menu oriented. COMNET III provides the smallest programming interface, and G2 has an easy to learn structured natural language. OPNET, Extend, and Workbench, each use a modified version of the C language. Workbench presents the user with the largest interface with the model's code, and provides the user with the most programming opportunities.

VIII. CONCLUSIONS

A. SUMMARY

Today's technological advances are nearly overwhelming. Increasing bandwidths, increasing data rates, new protocols and more, all lead to new equipment available for the military. The increased usage of COTS products encourages units to upgrade and replace existing capabilities.

The software products, analyzed in this thesis, can provide the user with a method for evaluating new equipment prior to its purchase. It, also, enables the user to optimize existing systems and networks, and to evaluate "what if" situations.

Each product has individual characteristics which make it the best choice for a particular user in a specific situation. This thesis evaluated five modulation simulator software products based on twenty-five evaluation criteria.

OPNET Modeler, by MIL 3 Inc., provides built-in familiar network icons. It provides the user with limited access to the code. The user can program entrance and exit criteria for low level states and processes. Access to code and debugging is in Proto-C. This can be troublesome for a non-programmer.

COMNET III, from CACI Products Company, is easy to learn. It provides quick high to intermediate level network modeling with familiar built-in icons.

Extend, developed by Imagine That Inc., is very user friendly. It does not contain network icons, but the user can build them. The product is flexible and can be used to model more than just networks, computers and communication equipment.

Workbench, created by Scientific and Engineering Software Inc., permits users to access the model's code. Network icons are not included, but can be created by the user or purchased for an additional cost. Access to the model's code and debugging the model are all completed in a language similar to C. These can be difficult for a non-programmer.

G2, by Gensym Corporation, provides a completely object oriented modeling environment. The documentation is very confusing. Programming is easy for non-programmers. It is completed in a structured natural language similar to the human language.

A user's needs and modeling and programming capabilities should be evaluated prior to choosing a software product. A weighted criteria evaluation is recommended for selecting the correct software tool.

B.   APPLICATIONS WITHIN THE MILITARY

The complex technology and the limited availability of troops and money provides an environment without the capability to fully test, evaluate, integrate, and analyze new equipment. Modulation simulators can be used to evaluate the integration of new equipment. New equipment can be modeled, tested and integrated for less money and with less troops than physically fielding a piece of equipment. Existing systems can be load-tested, reorganized, and reconnected. Outages and equipment losses can be simulated without the use of actual equipment and soldiers.

C.   RECOMMENDED FUTURE STUDIES

The software tools evaluated in this thesis can be used to model virtually any computer, communication, or information system. Future studies could include modeling and evaluating existing or emerging command and control or communications systems.

The growing inventory of modulation simulators has produced a concern for interface capabilities and limitations. This can be expanded to include uses and interfaces with virtual reality simulators.

Additionally, the Naval Postgraduate School is upgrading its existing internal computer network. The current and future networks could be modeled and analyzed for shortcomings and improvements.

APPENDIX. DEFINITIONS OF ASSESSMENT MEASURES

1. ACCESSIBILITY
   - Platforms supported
   - Conversion packages for switching to other platforms
   - Plans for support to any other platforms in the near future
   - PC version: DOS or UNIX based?

2. COMPLETENESS
   - Interactively models computers, software and communications equipment
   - Includes or is capable of modeling current and new computer architectures
   - Includes or is capable of modeling current and new LANs / WANs
   - Includes or is capable of modeling current or new mass storage devices
   - Includes or is capable of modeling Intra- and Inter- machine communications
   - Includes or is capable of modeling military communication devices

3. CONFIGURATION MANAGEMENT
   - Maturity of software
   - User view of the model

4. COST
   - Military acquisition prices (What extras are included?)
   - Maintenance costs
   - Training costs
   - Upgrade costs

5. DATA INPUT METHODS
   - Internal Methods
   - External Methods

6. DATA REDUCTION
   - How quickly

- What methods (Poisson, Wiebull, etc.)

7. DOCUMENTATION

- Requirements specification
- Design document
- Conceptual model document
- Tutorial
- User's Manual

8. EASE OF USE

- Support for computer/network modeling
- Support for software modeling (pre-analysis sizing, communications, functional flow, data flow, CPU loading, machine instruction specification, etc.)
- Support for data channeling modeling
- Support for communications traffic modeling
- Ease of learning
- Manuals readily available and easy to understand
- Set up time
- Run time
  * Can it be varied
  * Typical run duration

9. EXPERIMENTAL DESIGN

- Supports Monte Carlo
- Supports algorithms
- Iterative runs

10. EXTENDIBILITY

- Can tool be readily modified?
- Design or programmatic?
- What language?

11. EXTENSIBILITY OF RESULTS

- Alternative computer architectures
  * Extension to hypothetical architectures
  * Extension to architectures that may be performance tested
  * Extension to architecture that are not available for testing
- Alternative data channels
  * Extension to hypothetical architectures
  * Extension to architectures that may be performance tested
  * Extension to architecture that are not available for testing
- Alternative software descriptions
- Alternative communication requirements

12. FIDELITY

- Tool provides sufficient fidelity to ensure output accuracy across the tool architecture

13. FLEXIBILITY

- Can nodes move on line / off line? (How implemented)
- How quickly reconfigure?

14. INTEROPERABILITY

- Known interface capabilities (software / hardware)
- Interfaces under development
- Partial interfaces available (just the scenario?)

15. MISCELLANEOUS

- Terrain
  * Is it available?
  * Can equipment be tied to terrain?
- Frequency Management capabilities
- Outages
  * Planned / unplanned outages (How implemented?)
- Additional features

16. OPERATIONAL ENVIRONMENT

- System
- Portable
- Availability

17. POST ANALYSIS SUPPORT

- Reports (Variety)
- How quickly
- Graphs (Variety)

18. RELIABILITY

- Will it work every time producing the same results?

19. SECURITY

- Type of security (Classified or User)
- Labeling
- Passwords

20. SOFTWARE

- Process maturity
- Architecture
- Complexity
- Quality
- Reliability
- Sufficiency of testing
- Modularity or Object Oriented Design
- Maintainability

21. TRAINING / TUTORIAL

- Is it understandable? User friendly?
- Is it complete?
- How proficient is user after training? (overview, beginner, master)

22. TROUBLESHOOTING ASSISTANCE

- Is animation available
- Ability to view code (Can you see inside the model?)

- 1-800 help lines
- Frequent problems list / lessons learned

23. USER INTERFACE

- Type (Windows, C programming, UNIX programming, etc.)
- Quality
- Effectiveness

24. VALIDATION

- Degree of accuracy
- Variable (quick answer, intermediate answer, detailed answer)

25. VERIFICATION

- Of tool design and functions (How do we know it works?)

LIST OF REFERENCES

CACI Products Company, *COMNET III: Network Simulation Tool*, http://www.caciasl.com/comnet.html, April 1997.

CACI Products Company, *COMNET III User's Manual: Planning for Network Managers*, CACI, 1995.

Gensym, *G2: Reference Manual Version 4.0*, Gensym Corporation, 1995.

Gensym, "Gensym", http://www.gensym.com/products/g2realtime.html, May 1997.

Imagine That Inc., *Extend: Performance Modeling for Decision Support*, Imagine That Inc., 1995.

MIL 3 Inc., "Corporate Background", Prentice-Hall, 1987.

MIL 3 Inc., *OPNET Modeler Users Manual*, MIL 3 Inc., 1989 -1996.

Pressman, R.S., *Software Engineering: A Practitioner's Approach*, McGraw-Hill Inc., 1992.

SES, *SES/Workbench: Simulating Models*, Scientific and Engineering Software Incorporation, 1994-1995.

Sullivan, J.E., "A Computer Network Simulation Tutorial For COMNET III", Naval Postgraduate School, 1996.

BIBLIOGRAPHY

Advanced Research Center, "Computer, Software and Communications Simulation Tools: An Assessment of Current Technologies", Geshwind Associates, October 1992.

Bailey, Kemple, Chase., "Object-Oriented Modeling of Military Communications Networks", *Journal of the Operational Research Society*, Volume 45, Number 10, pp. 1108-1122, 1994.

Chinni, M.J., *Military, Government and Aerospace Simulation*, , The Society for Computer Simulations, Simulation Series Volume 28 Number 3, 1996.

Imagine That Inc., "About Extend", http://www.imaginethatinc.com, March 1997.

Jones, J.G., *Course Notes: Modeling and Simulation with COMNET III*, CACI Products Company, December 1994.

Madisetti, Gelenbe, Walrand, *Modeling, Analysis and Simulation of Computer and Telecommunication Systems*, IEEE Computer Society Press, 1994.

MIL 3 Inc., "OPNET Modeler", http://www.mil3.com/home.html, April 1997.

SES Inc., "SES", http://www.ses.com/www/workbench.html, March 1997.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
   8725 John J. Kingman Road, STE 0944
   Fort Belvoir, Virginia 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, California 93943-5101

3. Professor John Osmundson CC/Os 1
   Naval Postgraduate School
   Monterey, California 93943-5101

4. Professor Donald van Z. Wadsworth CC/Wa 1
   Naval Postgraduate School
   Monterey, California 93943-5101

5. Professor Dan C. Boger CC/Bo 1
   Naval Postgraduate School
   Monterey, California 93943-5101

6. Professor Paul H. Moose CC/Mo 1
   Naval Postgraduate School
   Monterey, California 93943-5101

7. Captain Heidi L. Gebhardt 1
   PO Box 265 31 Four Wheel Drive Road
   Warren, Pennsylvania 16365